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Assessing face mask littering in urban environments and policy implications: The case of Bangkok

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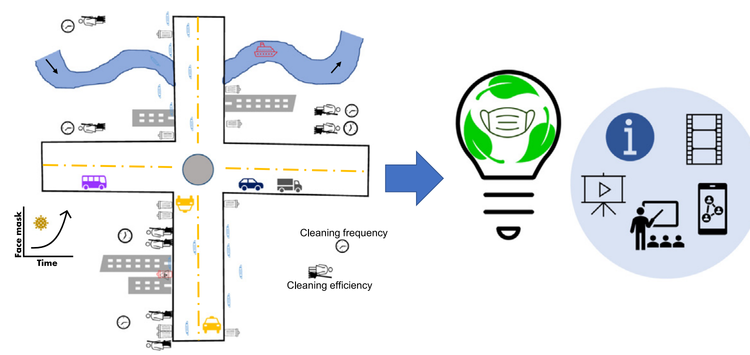
HIGHLIGHTS

- Mass use of face masks is causing an unprecedented influx of waste into the environment.
- Surgical masks are the most prevalent in use and are disposed of improperly.
- Awareness on mask handling and disease spread to inspire behavioral change
- Supporting research on the development of eco-friendly face mask is a sustainable solution.
- Fomenting national and international policies that curbs mask influx into the environment

GRAPHICAL ABSTRACT



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ABSTRACT

Face mask usage is one of the preventive measures encouraged worldwide to limit the transmission of the SARS-Cov-2 pandemic. Hence, production and mass use of face masks is on the rise due to the pandemic as well as government rules that mandate citizens to wear face masks. However, the improper disposal of face masks has been polluting the environment with enormous hazardous waste. In this study, a face mask littering assessment in an urbanized environment, Bangkok, was carried out. Three streets in the city were selected and observed for face mask littering for 5 h per day for 42 days. Moreover, a questionnaire from 605 participants was recorded to determine mask handling and disposal practices. The study found a total of 170 single-use face masks within a 13.30 km path. Furthermore, the highest (40) and lowest (17) cumulative litter were recorded on Sunday and Monday, respectively. Buffer analysis at 300 m showed 47% of mask litter was found within five mass transit stations, while 15% are within a single street market. Of 605 respondents, 82.15% used a single-use face mask. Surprisingly, most of them (70.58%) disposed of used face masks in regular bins along with their household waste. The results highlight three policy implications to tackle the growing problem: raising awareness, regulation, and provision of bins designed for used face masks in strategic places and supporting innovations and research for eco-friendly face masks.

1. Introduction

Since the outbreak of the contagious COVID-19 (Coronavirus of 2019) pandemic, the usage of face masks has been an essential safety measure to protect the public and health workers from viral infection. Face mask absorbs droplets released from the wearer and at the same

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[1] Surgical and Single-use face masks are used interchangeably throughout the paper to represent three-layer disposable face mask.

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time protects the wearer from inhaling pathogens in the air (Adanur and Jayswal, 2020; Chellamani et al., 2013; Colomer et al., 2021; Li et al., 2006; Metwaly et al., 2013). Due to the COVID-19 pandemic, many countries have enforced laws that mandate citizens to wear face masks in public places. As a result, the use and production of disposable face masks have skyrocketed since the outbreak of the disease. For instance, prior to the pandemic, the global market value of face masks was $737 million in 2019 and it is projected to reach $22,143 million at the close of 2021 (Markets and Markets, 2020). In the long haul, the global market for face masks is expected to see a sharp decrease to $3021 million by 2025. The trends in the projection indicate a meteoric rise in tandem with the extent of the success of global efforts to return to business as usual. One of the paths to attaining such a goal will be by reaching high levels of worldwide vaccine-mediated protection (Skegg et al., 2021). Until then, established measures like social distancing, hand washing, and masking will continue to be the norm. The obvious downside to the latter is the large volume of solid waste that will continue to be produced. Accordingly, the issue of face masks in the environment has received considerable critical attention from many researchers across the globe (Akhbarizadeh et al., 2021; Allison et al., 2020; Aragaw, 2020; Arimiyaw et al., 2021; Asumadu et al., 2021; Benson et al., 2021; Chau et al., 2020; Patrício Silva et al., 2020; Shettya et al., 2020). For instance, Ammendolia et al. (2021) did a survey to quantify the types of COVID-19 related PPE debris in Toronto, Canada. The finding showed that a total of 1306 PPE debris were found in the surveyed areas were face masks and constituted 31%. Similarly, a study done on the main tourist beaches in Chile determined an average of 0.006 face masks per square meter (Thiel et al., 2021). Moreover, the density of face mask litter was observed to be significantly affected by the activities of the beach in Lima, Peru, where recreational beaches were found to be the most polluted (De-la-Torre et al., 2021). However, banning single-use products was found to greatly reduce the amount of litter on beaches (Okuku et al., 2021).

Apart from the visual aesthetic damage to the streets, face masks could carry traces of pathogens that could pose a potential risk to human health. For instance, SARS-Cov-2[2] can remain infectious for a week in the outer layer of a face mask thereby constituting a potential threat to the occupational safety of solid waste workers (Chin et al., 2020). Another concern is that littered face masks can be transported farther by drainage systems, and wind up in the marine environment (Fadare and Okoffo, 2020). Hence, this creates additional marine debris that negatively affects the livelihood and survival of aquatic life. A report by OceansAsia detailing the presence of 70 disposable face masks on the remote beaches of Hong Kong in the early days of the pandemic, is a good case in point (Bondaroff and Cooke, 2020).

Furthermore, Haque et al. (2021) estimated the daily face mask waste of various countries in million tonnes, which were in the descending order of India (1.42) > Indonesia (0.45) > Nigeria (0.32) > Pakistan (0.23) > Bangladesh (0.19) > Iran (0.19) > France (0.16) > Philippines (15) > South Africa (0.12) > Ukraine (0.09) > Kazakhstan (0.03). In the same vein, Chowdhury et al. (2021) estimated the annual amount of discarded face masks that could end up in the ocean based on the population of coastal regions from 46 countries. Surprisingly, the estimated amount of face masks that could end up in the oceans ranges from 0.15 to 0.39 million tonnes a year. This is an additional waste to the existing solid waste that accumulates in the oceans annually. Another issue of concern to environmentalists is the generation of secondary microplastics due to the disintegration of face masks, which are predominantly made of PP (Polypropylene) and PE (Polyethylene) (Akhbarizadeh et al., 2021; Fadare and Okoffo, 2020). Experiments to demonstrate this fact could provide the knowledge basis to be able to model the influx of microplastics in the environment (Shen et al., 2021). The risk of pollution from secondary pollutants like dyes and surfactants is also plausible. For example, the leachability and solubility of dye compounds contained in disposable face masks increase the likelihood of their entering food chains and aquatic environments (Sullivan et al., 2021). In their capacity as chromophores, they are capable of disrupting ecosystems by reducing the photosynthesis of aquatic plants. In summary, these studies highlight the prevalence of face mask littering in different spheres of the environment. In this paper, for the first time, face mask littering and people's perception of mask handling and disposal in an urban environment were investigated by integrating field observation with questionnaires to develop policies to avert the problem.

1.1. The case of Bangkok

Face mask usage among Thai people is common due to either work-related exposure, during respiratory infectious bouts such as colds or flu or air pollution. However, face mask-wearing became more prevalent during the COVID-19 pandemic. According to Taylor (2020) survey, Thailand has a 95% face mask-wearing population, which is the highest number among the ASEAN countries. In line with the times, its face mask industry has grown dramatically to satisfy the demand during the pandemic. For example, in July 2020 the Department of Internal Trade's chief projected the daily face mask production to increase from 3.5 million to 4.2 million (NNT, 2020).

As of April 26, 2021, face mask-wearing was made officially compulsory for every outdoor activity in Bangkok, which will have a direct effect on the consumption of face masks. While face mask-wearing became compulsory for every outdoor activity in Bangkok by April 26, 2021, it had been the de facto norm in the early months of the country's first lockdown. The move to mandate public mask-wearing by the Bangkok Metropolitan Administration was in response to the higher infection rates that marked the third wave of the coronavirus. As a result, it sparked a surge in the amount of waste generated each day, which is creating a serious effect on the environment (Bangkok Post, 2021a, 2021b).

The present study focuses on single-use face mask littering in Bangkok, Thailand, and its policy implications. The main issues addressed in this paper are a) distribution of littered face masks along selected streets in Bangkok, b) people's attitude and precautions on face masks usage and disposal and c) people's perception of potential directives by the government and other stakeholders on tackling infections. In the end, policy recommendations were outlined to tackle the growing face mask waste and littering.

2. Materials and methods

2.1. Site description

Bangkok is the densely populated capital city of Thailand. The total area of Bangkok is around 1568.7 km^2 and it is home to more than 15% (~10.5 million) of the country's population. In this study, the Phaya Thai Road, Phetchaburi Road, and Ratchawithi Road were selected for the face masks littering observation (Fig. 1). Primary selection criteria for the three roads were 1) the traffic and commuters' density, 2) residential and commercial area, and 3) proximity to bus, Skytrain, and ferry terminals. Phaya Thai road is characterized by high traffic volume, three Skytrain stations (BTS[3]), one ferry terminal, and many bus stops on both lanes. The entire length of the road is majorly surrounded by commercial structures such as hotels, government offices, schools,

[2] Severe Acute Respiratory Syndrome Coronavirus 2.

[3] Bangkok Mass Transit System.

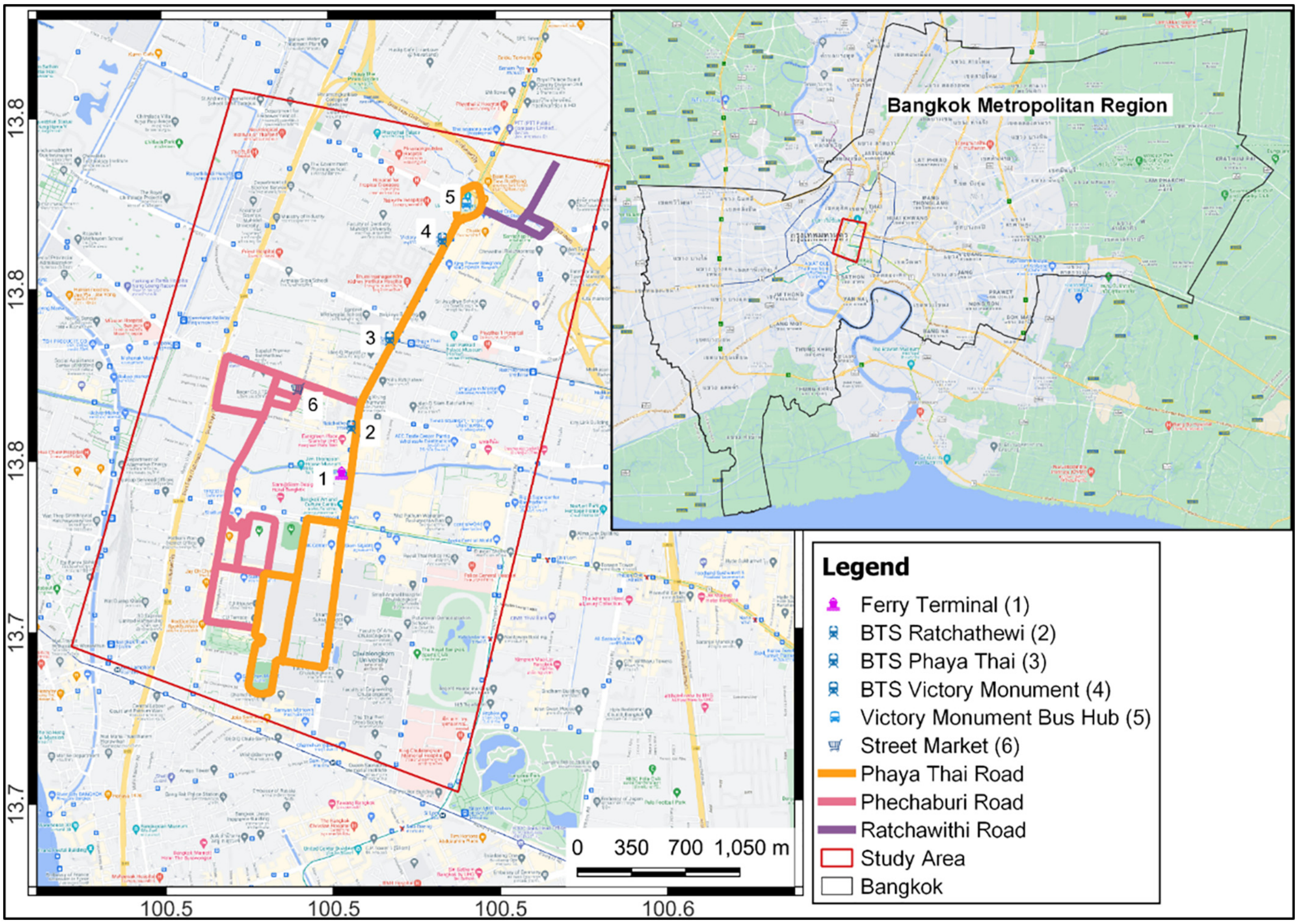

Fig. 1. Study area map showing Bangkok on the right and the surveyed area on the left.

universities, malls, fitness centers, restaurants, banking services, and mini shops (venders, hawkers, and 7–11), etc. The surveyed stretch of Phetchaburi road is largely dominated by residential buildings that also house small businesses. The area is dotted by a few schools, financial institutions, and outdoor flea markets. Ratchawithi Road has similar characteristics as Phetchaburi road.

2.2. Data collection

The study approach was twofold: one was visual observation and the second was a questionnaire to collect both quantitative and qualitative data. The visual observation was carried out from mid-January to February 2021 for a total of 42 days. The duration of the observation was between 9:00–12:00 a.m. and 7:00–9:00 p.m. GMT + 7. The time range was selected because it represents a day's worth of litter post morning cleaning and pre-evening cleaning, which starts at 10:00 p.m. During the observation, the area characteristics and geotagged photos were recorded for each littered face mask.

The web-based questionnaire was deployed from March to July and responses from 605 people nationwide were recorded. The questionnaire was prepared both in English and Thai language and distributed to Thais and foreigners. Moreover, to avoid confusion on technical terms within the questionnaire, illustrative photos were added. The questionnaire was designed to measure the following constructs: the first section elicited demographic information of respondents, followed by participants preferred type of masks and the reason for that, their practice on the use and disposal of the face masks, and their awareness of the effects of littered masks to humans and the environment. In the final section, participants were asked to respond to four Likert-type questions. The opinion statements were assigned with a numbering ranging from 1 (Strongly disagree) to 5 (Strongly agree). A pilot study was carried out on a small group before the full-scale survey. Then a reliability test was performed to determine the consistency and reliability of the questionnaire. The Cronbach's alpha value was ascertained to be 0.701. Descriptive statistics were done on the Likert-type responses and the mean of each question was labeled as very high (≥4.21), high (3.41–4.20), moderate (2.60–3.40), low (1.81–2.60), and very low (≤1.80). The levels were assigned by computing the increment from the number of levels divided by the difference of the maximum and minimum statement numbering (Eq. S1). All data analysis was performed by using SPSS[4] Statistics for Windows Version 22.

2.3. Spatial analysis of face mask littering

Spatial analysis was done using QGIS (Quantum Geographic Information Systems) to demonstrate the spatial distribution and density of face masks littering on the selected streets. Moreover, buffer analysis was done to capture the number of masks that had fallen within 100 m, 200 m, and 300 m of the BTS stations, bus hub, ferry terminal, and street market (Fig. 1). The buffer analysis is useful to understand the associations of population density and commuter movement on the distribution of face masks. Furthermore, the trend of mask litter throughout

[4] Statistical Package for Social Sciences.

the survey was computed based on a five-day frequency. The flux rate of face mask litter was also calculated to estimate the influx of litter in the environment.

3. Results and discussion

3.1. Face mask littering

The number and distribution of mask littering vary in both time and surveyed areas. Fig. 2 provides the sample pictures taken at different locations within the surveyed streets. For instance, in each street, the majority of littered face masks were observed along the sidewalk (72.9%) preceded by the street gutter (15.3%), traffic lane (10%), and waterways (1.8%). Surprisingly, most of the face mask types encountered were single-use face masks (98.3%). This study supports evidence from previous observations done in an urban environment of a community in regional Australia (Spennemann, 2021). The face mask litter captured floating on waterways implies their relocation from the land into waterways by stormwater runoff or wind. Another source could be direct littering on the waterways especially for the canals used for transportation purposes. The relocation of litter into another environment points to the potential impact that will be imposed on aquatic life since most of the mask litter ends up as microplastic in the oceans (Akhbarizadeh et al., 2021; Dong et al., 2021).

Although it is not statistically significant at a significance level of 0.05 ($p = 0.64$), temporal variations were observed among days of the week, wherein weekends had a higher number of face mask littering. As Fig. 3a shows, total face mask littering on Saturday and Sunday during the surveyed dates is 31 and 40, respectively, while on weekdays the total litter count ranges from 17 to 23. The higher number of masks littering on the weekends is connected to increased outdoor activities due to the days off. In a sense, some sort of a positive feedback loop might be at play. In this regard, a heightened perception of the risk of numerous people being outdoors drives more people to take extra measures of safety such as double masking or making multiple mask changes. An increase in outdoor activity over the weekend is characterized by many people taking leisurely walks, runs, and running errands owing to having more personal time. Conversely, weekdays are characterized by a large swath of workers and students working remotely from home. It might be argued that the pandemic has encouraged a massive shift towards a preference to online purchase as oppose to frequenting shopping centers in person. Hence, the weekends present a chance to break away from the five-day workweek indoor routine. Both unpublished and published studies by Duc Huynh (2020) and Bourne et al. (2021), respectively, confirmed that the likelihood of people wearing medical masks in nonmedical settings rose with the perception of the risk of developing COVID-19. In addition, the spike in mask littering on weekends is linked to the rigidness of the cleaning schedule that fails to account for the peak in outdoor activities over the weekend or at other times.

Mask littering showed an increasing trend during the period of data collection. The five-day cumulative sum of face mask littering is shown in Fig. 3b. In the early days of the data collection, the cumulative sum was almost constant with irregular peaks and troughs in some days. Then starting from the first week of February, the running total shows a sharp increase and reaches a peak of 49 at the end of February. The increasing trend might be associated with the second wave of the COVID-19 pandemic that started in mid-December. Since the onset of the second wave, the number of infections in Bangkok has been on the rise, prompting a corresponding increase in public usage of face masks. For instance, the daily number of COVID-19 infections in Thailand reached a record of 937 on January 26, 2021 for the first time since the start of the pandemic (DDC, 2021) (Fig. S2). Similarly, in Bangkok, an average of 11.48 t of face masks per day was discarded starting from the end of 2020 and the beginning of 2021. Then the tally of discarded face masks rose to 12.92 t per day in April during the third wave of the COVID-19 outbreak (PR Bangkok, 2021). This trend is in line with a study in the USA which established that COVID-19 deaths influenced the mask-wearing rate among the public (Hao et al., 2021).

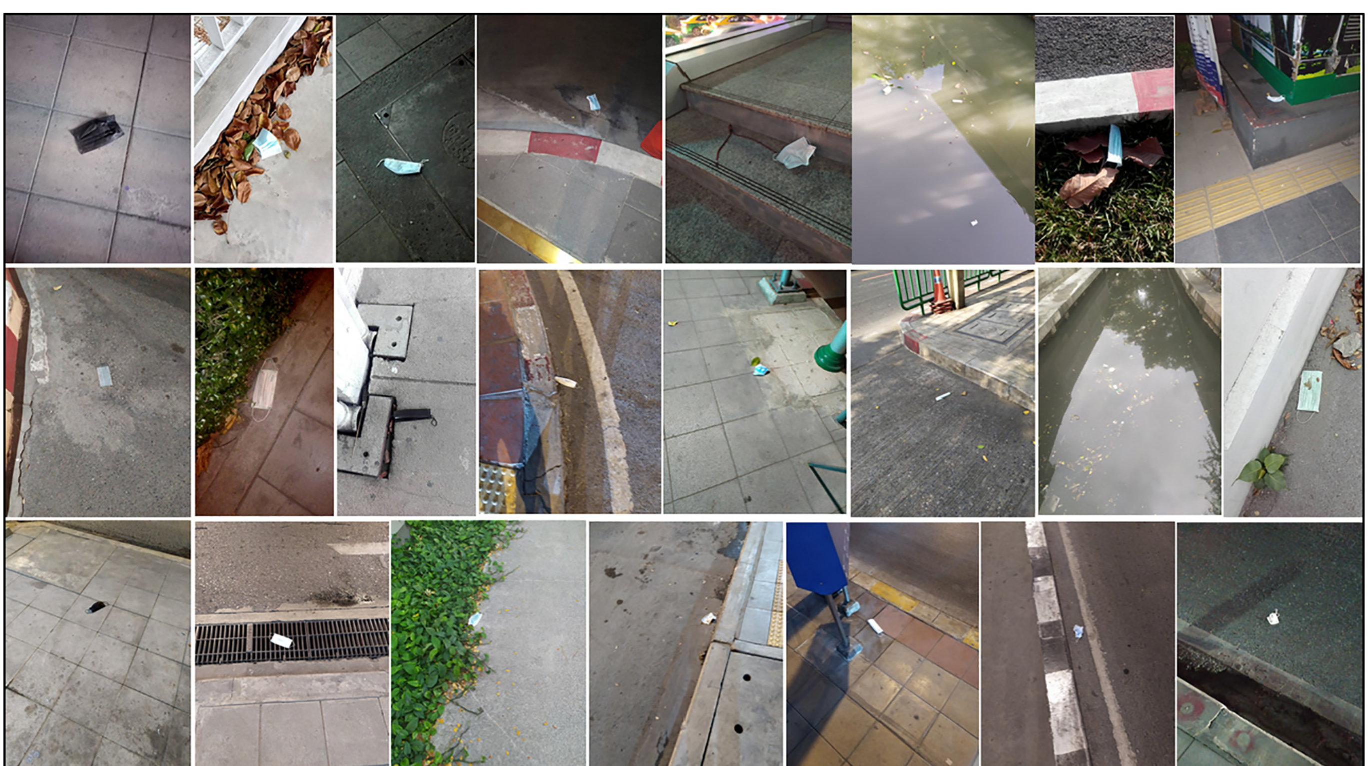

Fig. 2. Face mask litter along sidewalks, street gutter, and waterways in Bangkok.

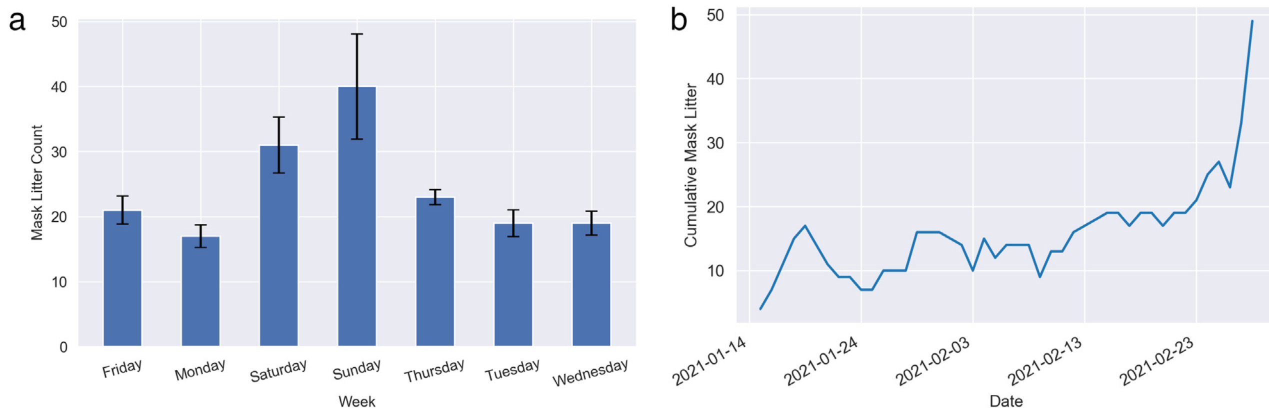

Fig. 3. Face mask count during the survey dates a) cumulative variation among the days of the week and b) five-day cumulative sum of mask litter.

According to the Department of Pollution Control, under a single-use scenario, an estimated 1.8 billion face masks are discarded nationwide each month, with many of them disposed of improperly (Bangkok Post, 2021b). Given that ~15% of Thailand's population resides in Bangkok, the monthly amount of face masks discarded in the capital will be 270 million. In the same vein, using a 3% conservative loss rate usually applied to the number of plastics that end up in the oceans, an estimated 8.1 million face masks end up in ocean waters monthly. This implies that around 1080 t of face mask waste are generated in Bangkok monthly, and of those numbers, 32.4 t could end up in the oceans via the city's numerous canals. However, the estimation can be higher due to more than one layer of mask use. For instance, when the number of COVID-19 cases was increasing, some people were observed to use double to triple layers of face masks which could have potentially increased the usage and disposal of face masks (Bangkok Post, 2021c). The practice of wearing more than one mask with the onset of subsequent waves of COVID-19 might have arisen from panic or the perception that more than one mask would be more effective. Overall, the potential to cause disaster to an already struggling municipal waste management system is a reality local authorities are concerned about (Bangkok Post, 2021b; Sun et al., 2020).

The total quantity of face mask litter over surveyed dates was 173, of which 3 (1.7%) were cloth masks (Fig. S1), while the single-use face masks were 170 (98.3%). Interestingly, the observation indicates that single-use face mask littering is more likely than its counterpart cloth mask. Furthermore, the daily flux rate of face masks litter at the Phaya Thai Road and Ratchawithi Road are 0.38 and 0.36 pcs km^{-1} day^{-1} respectively, which is higher than that at the Phetchaburi Road (0.20 pcs km^{-1} day^{-1}) (Table 1). These results reflect those of Ammendolia et al. (2021) who also found that the daily mean density of mask littering varies from 0.00475 to 0.0020 items m^{-2} in selected areas in Toronto, Canada. Assuming each face mask weighed 4 g, the total mass flux rate in all surveyed Roads is 1.22 g/km day^{-1}. However, per day represents the duration of time the observation was carried out, which is 5 h daily.

Table 1
Flux rate of single-use face masks in all surveyed roads.

Surveyed roads	Mask litter	Distance (km)	Flux rate	
			(pcs/km/day[a])	(g/km/day[a])
Phaya Thai Road	105	6.60	0.38	1.52
Phetchaburi Road	47	5.50	0.20	0.80
Ratchawithi Road	18	1.20	0.36	1.44
Total	170	13.30	0.30	1.22

[a] Day represents only the duration of the observation hours (5 h).

3.2. Spatial distribution of face mask litter

As shown in Fig. 4, the spatial distributions of face mask litter vary across all surveyed roads. The total mask litter count in descending order is Phaya Thai Road (56.5%), Phetchaburi Road (33.5%), and Ratchawithi Road (10%). Within each road, there are places with a higher density of face mask litter, while other places are either sparse or without litter. The possible reason can be attributed to the activity of the road and population density. In order to assess mask littering in the selected stations (Ferry terminal, bus hub, BTS station, and street market), buffer analysis at 100 m, 200 m, and 300 m was done and the percent of face masks that intersect each buffer line was presented.

Buffer analysis of 300 m reveals that mask littering is higher around the street market, which accounts for 15% of the total litter (Fig. 5). This is followed by BTS Ratchathewi (12%), BTS Phaya Thai (11%), ferry terminal (10%), Victory Monument bus hub (8%), and Victory Monument BTS (6%). The percentage of litter in the 200 m buffer is as follows: street market (18%), ferry terminal (16%), BTS Phaya Thai (9%), and the other three locations have 8% each. The ferry terminal has the highest (9%) litter within 100 m buffer, while the other locations have less than or equal to 6%.

Phaya Thai district which shares a border with Ratchathewi lies to its north. All but one of the BTS stations (Phaya Thai BTS) indicated in the map (Fig. 4) is in the latter. Based on observation, the percentage of face masks litter was higher in the Ratchathewi district than in the Phaya Thai district. The percentage of face mask sightings was higher at BTS Ratchathewi (12%) than at BTS Phaya Thai (11%). A number of reasons can be attributed to this observation. First, the Ratchathewi district boasts a higher population density albeit marginal when compared to its northerly neighbor. Second, it is more accessible as it is reachable by both land and water. The proximal location of the Ferry Terminal to BTS Ratchathewi implies the surrounding area serves as an initial landing for the large influx of commuters. Across the board, the percent of face mask litter is lower in Phaya Thai partly because of the nature of population distribution. For instance, the bulk of the population is concentrated in the Saphan Kwai area, while the eastern half is occupied by several military facilities. BTS Victory Monument recorded the least (6%) face mask litter sightings. It may be argued that these findings are associated with the strategic siting of the station: south of a historic national landmark and a major traffic intersection in Bangkok. Furthermore, access to the station from all corners of the traffic circle is by a skywalk. A major bus hub and van terminal are in the vicinity of the station. Since the prerequisite for passengers to get on any vehicle of transportation is to have masks on, there is a greater sense of responsibility on the part of commuters to always have this item handy. Mask sighting numbers for BTS Victory Monument and the Victory Monument Bus Hub are comparable because they operate in the same vicinity under

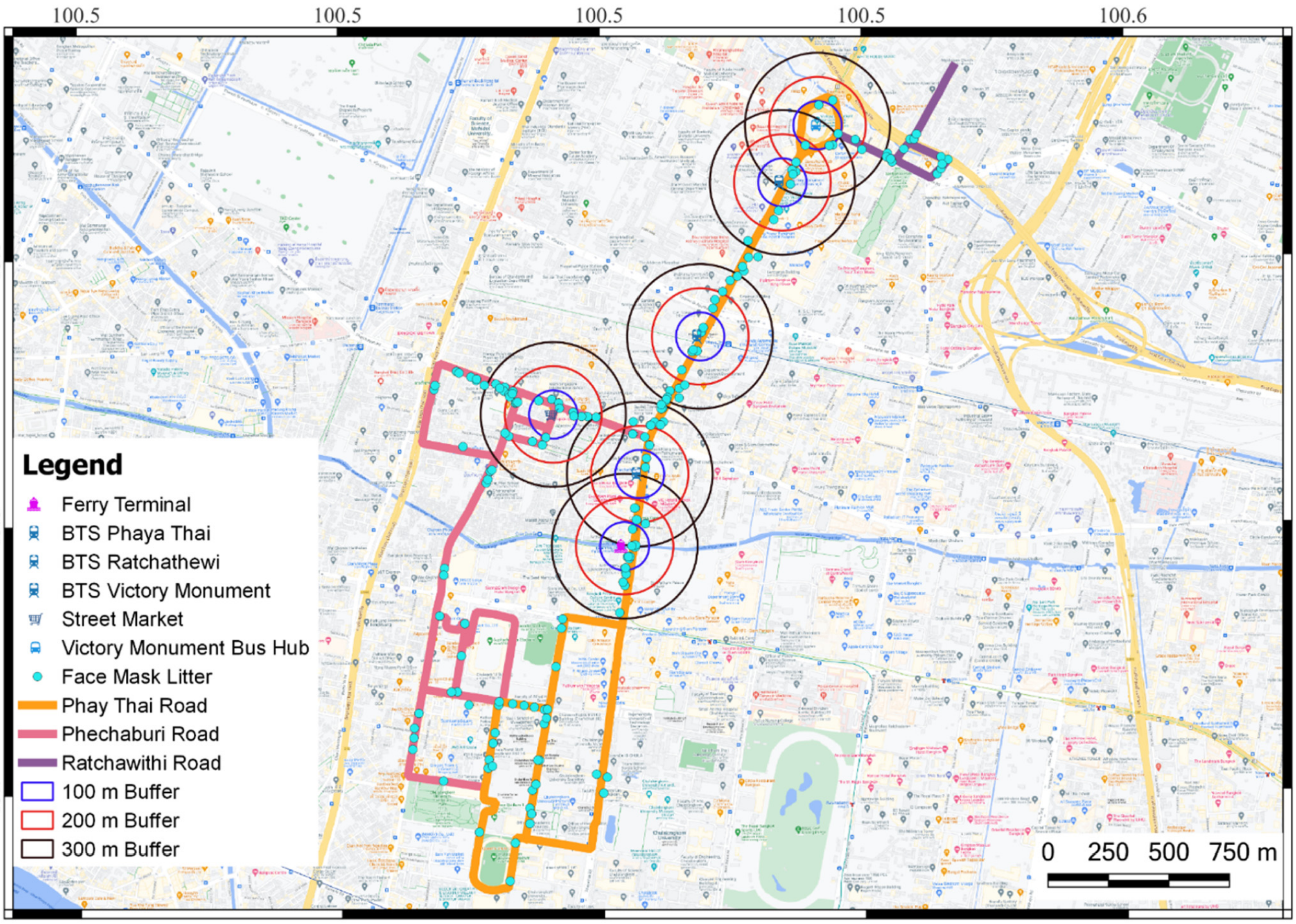

Fig. 4. Map showing buffer locations and spatial distribution of face mask litter.

similar rules. Another reason worth considering is the huge proportion of the commute underneath the skywalk by car limits the chances of people dropping face masks. The walkway, on the other hand, is staffed with cleaning operatives to tidy up trash promptly.

With regards to the quantity of masks litter observed, the street market had the highest number of sightings (15%). The high concentration of people in the area, insufficiently and strategically poorly placed waste receptacles that fail to meet the needs of marketgoers, creates an area prone to littering. For example, more waste receptacles could be stationed along the numerous alley's marketgoers and inhabitants in the vicinity use. The presence of multiple street-side market stalls makes cleaning very challenging for waste workers. As a result, there is a tendency for litter to be displaced to places not readily within sight of waste workers who largely focus their effort on waste pickup points. This litter build-up in the vicinity of the market, a product of passive and active littering, encourages the littering behavior of others as has been previously demonstrated in numerous studies (Dur and Vollaard, 2015; Keizer et al., 2011; Rangoni and Jager, 2017).

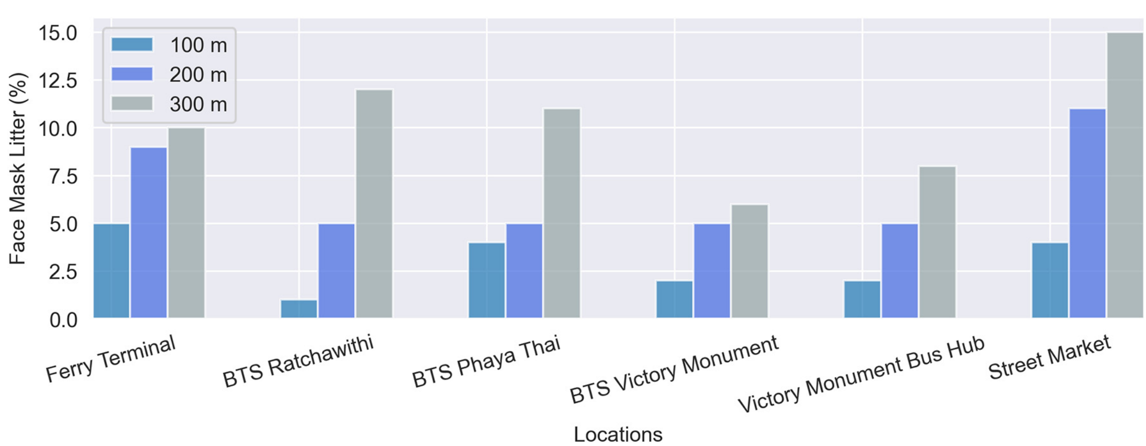

Fig. 5. Percent of face mask litter within 100 m, 200 m, and 300 m buffer zones.

Table 2
Demographic profiles of respondents.

Items	N	%	Items	N	%
Gender			Education		
Male	169	27.93	Primary school	3	0.50
Female	430	71.07	Vocational diploma	14	2.31
Other	6	0.99	High school	73	12.06
Age			Bachelor's degree	386	63.80
15–17	48	7.93	Postgraduate	129	21.32
18–35	259	42.80	Nationality		
36–50	241	39.83	Foreigner	61	10.08
51–65	54	8.92	Thai	544	89.91
65 and above	3	0.50			

3.3. Survey findings

The sample ($n = 605$) had a majority female (71.07%) and a minority of not specified sex (0.99%) demography. The demographic characteristics namely gender, age, education, and nationality of the respondents are described in Table 2.

3.3.1. Single-use face mask usage

The opinion statement of the respondents along with descriptive statistics is given in Table 3. Overall, the attitude of the public towards the usage and enforcement of face masks is very positive. The positive acceptance of face mask is in accord with a previous study finding that showed a 95% mask-wearing acceptance rate among Thai people (Taylor, 2020). Furthermore, responses indicated that there is a need for information dissemination on the proper use and disposal of face masks. For example, public health media campaigns could improve awareness on the potential risk of self-contamination due to poor handling of face masks and eventual touching of eyes with contaminated hands. The knowledge that improper disposal of face masks compounds the risks of contamination of street cleaners is also of vital importance. There is ample evidence that human coronaviruses can remain viable and infectious on inanimate objects at room temperature for up to nine days (Kampf et al., 2020). The duration of this persistence falls with temperatures above 30 °C. These kinds of information have the potential to indirectly increase a person's perception of risk and ultimately nudge them towards compliance with public health measures (Nivette et al., 2021).

Favorability for opinion statement three ranks the least (3.75). A plausible reason for this is the notion that a face shield alone does not provide adequate protection from spreading or contracting the disease. Furthermore, the incidence of people with respiratory conditions that might warrant them to opt out of wearing a mask is low. By implication, many of the respondents might not be acquainted with individuals with such special needs.

The majority of the respondents (83.80%) said they use a single-use face mask, while 12.89% do not. Moreover, 3.31% of respondents use it occasionally. Similarly, 82.2% of respondents preferred to use single-use face masks, a number that outnumbers those opting for cloth masks (12.89%). The remainder preferred N95 face masks (3.64%) and others (1.32%). This finding is consistent with that of Abdoul-azize et al. (2021) who found a 66% and 34% preference for single-use and cloth masks, respectively, among Turkish people. The consistency of the proportion of respondents who use and prefer single-use face masks suggests the prevalence of single-use face masks among the public. The result agrees with the type of litter encountered on the surveyed streets wherein single-use face masks comprised 98.30%, while cloth masks constituted only 1.70% (Section 3.1). A similar study done in Hong Kong showed 47% prioritization of single-use face masks over the counterpart cloth mask (14%) (Knott, 2020). On the other hand, the preference is contrary to the type of mask-wearing among taxi drivers in Dessie City, Ethiopia. In this study, the majority of the taxi drivers use cloth masks (58.3%), followed by N95 face masks (24.5%) and surgical masks (17.3%) (Natnael et al., 2021).

Overall, the respondent's reasons for preferring single-use face masks were as follows: convenience (63.64%), effectiveness (47.30%), and affordability (17.67%). The convenience of single-use face masks is attributed to the breathability, lightweight, and disposable nature of the mask. Effectiveness represents the ability of the face mask to protect the wearer from a virus. The result implies the superiority of single-use face masks in providing ease of use, good filtering capacity, and better breathability over cloth masks (Tcharkhtchi et al., 2021). Furthermore, a single-use face mask is much cheaper than its counterpart cloth mask. For instance, one single-use face mask costs from $0.05 to $0.08, while a cloth mask costs from $0.51 to $2.25. The large price difference added to the convenience that the single-use face mask provides makes it the perfect choice among the wearers.

3.3.2. Face mask handling and disposal

Approximately three-quarters of the respondents (76.20%) use a face mask for one day, while 20.99% use it for more than one day. On the other hand, 1.16% of the respondents use a face mask for a half-day, while 1.65% do not use a single-use face mask. When asked whether they practice mask handling precautions in their use of a face mask throughout the day, the majority of the respondents (71.74%) commented that they do, while almost one-fourth (20.17%) reported they do it occasionally. The minority of the respondents (8.10%) replied they do not practice any mask handling precautions. Although most of the respondents show a high level of awareness, the findings suggest that there is still a lack of awareness among a handful of the populace. In accordance with the present results, previous studies have demonstrated that an awareness campaign is the best solution for better and safe use of face masks (Beckage et al., 2021).

When the participants were asked how they dispose of the used face mask, the majority (70.58%) commented that they used regular bins. Moreover, 3.14% and 1.98% of the respondents used plastic bags and plastic bottles, respectively, to bag or bottle the mask before they disposed of it in a regular bin. On the other hand, 22.64% of respondents stated they use a hazardous waste bin to dispose of the face mask. The remainder indicated that they burned the mask (0.66%), put it in a bin designated for a face mask (0.34%), and threw it anywhere (0.17%). In an effort to aid the proper disposal of medical waste and used face masks, the Bangkok Metropolitan Authority has made available designated bins in several locations across the capital (PR Bangkok, 2021). However, these bins might be inadequate to bring about a positive result. The finding indicates that most of the face masks are disposed of improperly without separation, which could end up in a landfill, incinerator, or displaced to the environment. For instance, in Bangkok, 90%

Table 3
The rating of opinion statements of face mask usage.

Opinion statements	Mean	SD	Level
1. Media and health professionals should disseminate information on how to use and dispose of face mask	4.59	0.64	Very high
2. Government should impose fines on people who violate regulations on wearing a mask in public places	4.29	0.90	Very high
3. Face shields should be the prescribed public alternatives for those having a hard time wearing single-use masks	3.75	1.15	High
4. Guidelines on the use of masks in both private and public establishments should be uniform	4.49	0.71	Very high
Average	4.28		

of waste generated is collected, and from that, 87% goes to landfills (Sun et al., 2020). Another concerning issue is the occupational safety of waste scavengers due to the mixing of general waste with infectious waste. Used masks stuffed in plastic bottles pose a higher risk since the waste pickers target recyclable materials. According to the Pollution Control Department (PCD), there was a case of COVID-19 infection in Thailand caused by a contaminated mask inserted in a plastic bottle (Bangkok Post, 2021d). Although the PCD report does not fully explain how they came to that conclusion, the occupational risk is plausible.

Almost three-quarters of the participants (76.36%) reported that they do not sanitize the face mask before disposal. In contrast, 13.39% of the respondents sanitized occasionally, and 10.25% sanitized every time they disposed of the face mask. Furthermore, 60.33% of the respondents commented that they never saw bins designated for face masks, while 38.34% said that they seldom saw mask bins. Interestingly, 1.32% of the respondents said they often encountered bins specified for a face mask. These results further support the need to increase trash bins designated for face masks that the public can easily access.

When asked whether they encountered face mask litter, 61.49% of the respondents reported that they had seen it occasionally. Slightly below one-third of the respondents (31.57%) said they often encountered littered face masks. A minority of participants (6.97%) indicated that they had never seen littered face masks. Mass use of face masks will likely increase with increasing infection rates. As a result, mask littering and the potential impact on the environment will persist (Ammendolia et al., 2021; Roberts et al., 2020). Almost half of the respondents (48.76%) commented that littered face masks posed a risk to human health, while more than one-third (39.34%) reported it might pose a risk to human health. Surprisingly, 11.90% of the respondents replied that littered masks posed no risk to human health. These results reflect those of Botetzagias and Malesios (2021) who also found that single-use mask users have lower awareness of the environmental impacts of face masks than their counterpart cloth mask users in Greece. The result suggests the need for information dissemination to raise public awareness.

3.4. Policy implications

The study findings indicate a need for a comprehensive array of policy solutions to mitigate the environmental damage occurring due to discarded surgical face masks, especially in risk-prone areas in urban settings. The recommendations put forward apply largely to these kinds of urban contexts and acknowledge the simultaneous existence of other realities even within the same urban area. Furthermore, the formulated solutions ensure lower environmental impact without compromising public health safety. Therefore, in this paper four policy recommendations are proposed to tackle the effects of mask littering.

Firstly, there is a need for an awareness campaign to raise people's knowledge on the safe practice and disposal of face masks. These can be done through various platforms such as mainstream media, social media, posters, etc. For instance, short videos containing face mask handling information can be played on mass transit screens. The campaign to inspire behavioral change can be further advanced by decentralizing efforts on public awareness. For example, communities can fly banners encouraging mask-wearing and personal responsibility in safe disposal at crucial entry and exit points in their locality.

There is a need to have trash bins designated for face masks to avoid the mixing of infectious waste with regular waste. Although that could be challenging in developing countries giving the current solid waste management system, an alternative solution could be to install the face mask bins in front of convenience stores since they are distributed widely among communities. Furthermore, setting up face mask bins in strategic places such as mass transit stations, malls, street markets, apartment complexes, and people congested areas can discourage people from littering. A city like Bangkok has a lot of apartment complexes and residential estates, wherein proper waste management varies widely. A government-mandated guideline that reflects the current circumstances could go a long way to address some of the problems faced pre- and post-pickup by waste handlers. For example, the provision of close lid bins and the meticulous bagging of masks in color tagged bags, preferably eco-friendly, to ease sorting during garbage pickup. To illustrate, these disposable masks could be placed in yellow plastic bags to indicate their infectious nature, while black bags could represent non-recyclable waste. Additionally, the periodical decontamination of these designated bins can be implemented by waste handlers empowered with knowledge from state-funded programs on how to appropriately deal with medical waste to curb the risk of infection. The understanding that the presence of litter in an environment encourages more littering in the area can be discouraged by adopting the strategy of quickly removing litter or increasing the frequency of the cleaning regime.

Secondly, the higher acceptance rate of surgical face masks over the counterpart cloth masks is indicative of the necessity for an alternative eco-friendly face mask. A revolutionized cloth mask, with better filtration and breathability, can be a good candidate. To facilitate this process, the services of AFNOR,[5] a French standardization firm, could be hired to devise a minimum local requirement for cloth masks alongside training local scientists (SGS, 2020). Since it is reusable, the influx of face masks can be significantly reduced. In addition, governments should promote and subsidize the price of cloth masks to encourage a change in consumer behavior. For example, NCIRD[6] USA has been disseminating guidelines on the safe use of face masks and has been promoting the use of cloth masks since the early days of the COVID-19 pandemic (NCIRD, 2021). Moreover, academic institutions can design and encourage cloth masks use with matching school colors or student uniforms.

Furthermore, there is a need of stepping up investment in innovative research on biodegradable face masks of comparable or better quality than surgical masks. Research by Choi et al. (2021), for example, was able to develop a more effective, breathable, and biodegradable mask filter. The mask filter was prepared by fabricating a Janus membrane that was subsequently integrated with microfiber and nanofiber mats. Interestingly, the mask filter could be degraded completely in four weeks in composting soil, contrary to a surgical mask that could take more than 400 years (Bondaroff and Cooke, 2020).

The success of the above-mentioned recommendations will be of little consequence without the involvement of government institutions to limit the impact of face masks. Enforcing existing legislation such as fines for littering while incentivizing and supporting innovations for reusable face masks are approaches worth pursuing, nationally and internationally. For instance, the presence of improperly discarded face masks in oceans or international waters brings about problems that affect the wider regions. Therefore, the efforts of a single nation to avert suchlike problems will come to naught without international cooperation. The focus of such cooperation could center around the development of common strategies to limit the influx of disposable face masks into the environment. While there is importance in enforcing existing regulations at all levels of jurisdiction, regularly updating market-based instruments complements the benefits of the former in encouraging a behavior change.

In sum, any success at limiting face mask litter will entail an emphasis on inspiring behavioral change via public awareness education, creating environments that facilitate good behavior via the strategic placing of specialized waste receptacles, raising people's acceptability of cloth masks, dispensing more funds for innovative research on eco-friendly face mask varieties, and solidifying national and international cooperation to curb mask influx into the environment.

[5] Association Française de Normalisation.

[6] National Center for Immunization and Respiratory Diseases.

3.5. Limitation of the study

In this research, there are some notable limitations. The first limitation is linked to the field survey of mask litter. Because of time and logistic constraints, surveys were conducted disproportionately on one side of the two-lane roads once a day at different time intervals. The second limitation is the gender distribution of respondents. In that regard, the responses are overrepresented by female respondents.

4. Conclusion

The present study found that face mask littering is a serious problem in Bangkok. The average flux rate of the face mask was 1.22 g/km/day. Moreover, face mask littering within 300 m buffer is higher around street markets (15%) and five mass transit stations (47%). Temporal variations of littering were found to be higher on weekends. Overall, compliance with public health guidelines of wearing a face mask during outdoor activities is very high. Surgical masks are the preferred type of mask among the public due to convenience (breathability, lightweight, and disposability), perceived higher filtration efficiency, and affordability. However, public awareness of the proper use and disposal of face masks is still low. Given that the COVID-19 pandemic is far from over due to viral mutations, disproportionate vaccine distribution, and conspiracy theories, governments will likely continue to embrace precautionary measures like wearing face masks during outdoor activities. Moreover, future pandemics remain possible due to the ecological process, socio-anthropogenic process, and population growth (Thoradeniya and Jayasinghe, 2021). Consequently, mass use of face masks will continue to affect the environment as a new source of infectious waste and secondary microplastic. Therefore, policy intervention is inevitable for the sustainable use of face masks to ensure public health safety without compromising the environment. Policy interventions such as educational awareness, support for research on reusable and biodegradable face masks, enforcing existing regulations, and strengthening international cooperation are the way forward. Further research on discarded masks utilization is required to minimize the influx of waste to the environment. In addition, studies could be conducted on how to model risk prone environments to inspire behavioral change.

CRediT authorship contribution statement

Yacob T. Tesfaldet: Conceptualization, Writing – original draft, Writing – review & editing, Visualization. **Nji T. Ndeh:** Writing – original draft, Writing – review & editing, Visualization. **Jariya Budnard:** Writing – review & editing, Data curation. **Patamavadee Treeson:** Writing – review & editing, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.150952.

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